

4.4 Ga alteration of chondrules in Allende (CV3) parent body: evidence from the Rb-Sr system.

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Introduction: It has been revealed that both of the thermal and aqueous alteration had occurred in the CV parent body [1, 2, 3]. To give a constraint to the alteration processes, the Allende meteorite can be a best example, because the following results indicate that the Allende is the strongest altered meteorite among the CV chondrites, those are: (a) homogeneity of the olivine in matrix of the CV3 chondrites increase from Kaba, Mokoia, Vigarano, Grosnaja to Allende [4, 5]; (b) Allende is markedly depleted in noble gases [6] (c) the abundance of interstellar SiC content decreases significantly from Leoville, Vigarano and Efremovka to Allende [7, 8].

To examine the alteration processes of the Allende meteorite, Rb-Sr system is suitable, because the disturbance of the Rb-Sr system of the Allende chondrite has been reported [9, 10, 11]. Since the opaque assemblage in the CAIs, chondrules and matrix of the Allende chondrite had equilibrated at the similar temperature [12] and since the disturbance of the Rb-Sr system of chondrules is identical to that of the CAIs [9,10], the alteration processes affected the Allende inclusions identically. To avoid the differences in the chemical and thermal properties among the inclusions, it should be better to limit a target. Among the inclusions, the chondrules should be suitable, because they have wide variety of chemical compositions, especially in alkaline metal elements. Additionally, to reduce the effect of relict minerals, we focused upon the barred olivine chondrules. The petrographic type and the degree of alteration for the individual chondrule were also determined. In this study, we have improved our preliminary work [11] and give a new insight into the alteration process in the CV parent body. The major goal of this study is to elucidate of the alteration process in the CV parent body based on the Rb-Sr system of the Allende chondrules.

Result: Studied chondrules cover the various types of texture, i.e., five porphyritic chondrules, eleven barred olivine chondrules and one radial pyroxene chondrule. All of these chondrules have nepheline or sodalite in mesostasis. This fact indicates that the alteration affected all chondrule in this study [13, 14]. In order to evaluate the effect of the alteration process upon the chondrules, the degree of alteration was qualitatively classified by the existence of nepheline or

sodalite in the mesostasis of the chondrule, i.e.; (1) degree "A" indicates slightly altered chondrule, in which nepheline and sodalite only exist periphery; (2) degree "B" indicates moderately altered chondrule, in which nepheline and sodalite occur throughout the chondrule and primary mesostasis remain only in the center of chondrule; (3) degree "C" indicates extremely altered chondrule, i.e., there is no primary mesostasis in a chondrule.

The isotopic ratios of the chondrules and the whole rock samples are plotted in $^{87}\text{Sr}/^{86}\text{Sr}$ evolution diagram with 4.56 Ga reference line (Fig.1). The result shows that the chondrules are scattered on the diagram along with 4.0 Ga reference line of which $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratio is 0.6997 ± 0.0014 . Consequently, we fail to yield an internal isochron age. Since the three independent works obtained identical trend (Fig. 1), the trend is essential for the Allende chondrules.

Summary: The isotopic composition of the Allende chondrules are scattered along with 4.0 Ga reference line on the $^{87}\text{Sr}/^{86}\text{Sr}$ evolution diagram. Consequently, we fail to obtain the internal isochron age of the chondrules as well as previous works. Since this disturbed Rb-Sr system suggests that the alteration process occurred long after the formation of the parent body, it is indicated that the alteration process had occurred in the parent body. To obtain a constraint for the alteration process, the degree of alteration was determined for the each chondrule based on the distribution of secondary phases (nepheline and sodalite) in the chondrule. The result shows that there is no specific relation between the degree of alteration and the disturbance of the Rb-Sr system of the chondrules. Hence the disturbance of the Rb-Sr system was not caused by the production of the nepheline and sodalite. This notion is consistent with the petrographic works [12, 13], because they insisted on that these secondary phases were produced in the nebula.

The diagram of $1/\text{Sr}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ suggests that three components mixing can be responsible for the disturbance of the Rb-Sr system of the chondrules. Furthermore the correlation diagram between K and Rb indicates that the one of three components would be the secondary phases (nepheline and sodalite) in the chondrule. The relation between Rb and Sr of the chondrules suggests that other two end components

have the following chemical characteristics, i.e., one has relatively high Sr and Rb concentration with Rb/Sr ratio similar to the Allende whole rock and the other has relatively low Rb and Sr concentration with Rb/Sr ratio also similar to the Allende whole rock. Take the mineral assemblage of chondrule into account, above two components would correspond to the mesostasis and the phenocrysts (olivine and pyroxene), respectively. Since it had been suggested that the phenocrysts are free from the alteration process and since the mesostasis should be easily affected by the alteration process, we consider that the mesostasis is a key component of the parent body alteration process. In this point of view, we selected the mesostasis-rich chondrules with a simple criterion, i.e., Sr concentration higher than the Allende whole rock. The selected seventeen chondrules including literature data show a close correlation with an age 4.351 ± 0.120 Ga (Fig.2). Since the $^{87}\text{Rb}/^{86}\text{Sr}$ ratios of these chondrules are covering nearly entire range of $^{87}\text{Rb}/^{86}\text{Sr}$ variation of all chondrules and these chondrules are from three independent works, this correlation would not be caused by coincidence such as sampling effect. Instead, the most plausible explanation of this correlation is that it represents an age of the parent body alteration. Since there are chondrules which deviate from 4.4 Ga reference line, the parent body alteration process is not a single event but rather continuous or intermittent events, such as a condition of gradually cooling parent body or long-term heavy bombardments by meteorites.

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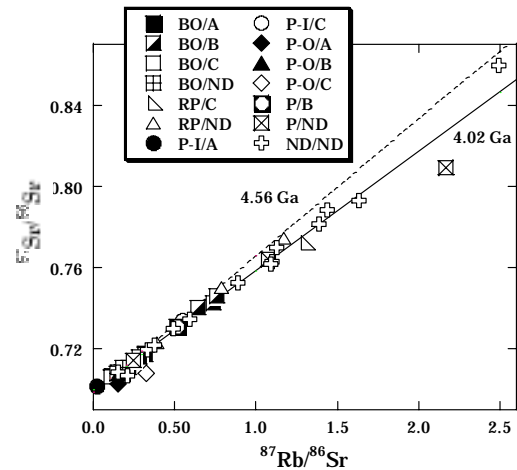


Fig. 1. Rb-Sr evolution diagram for the chondrules, showing the relation between the petrographic type and the degree of alteration of the chondrule. The textures of chondrules are described with abbreviation P, BO or RP indicating porphyritic, barred olivine and radial pyroxene chondrules, respectively. The degree of alteration of chondrule is also shown as A, B or C which indicates least, moderately, and extremely altered chondrule, respectively. ND is abbreviation of "not determine". I and O indicate inner and outer part of chondrule, respectively. This diagram includes literature data from Gray et al., 1973 and Tatsumoto et al., 1976 (most of these are ND/ND).

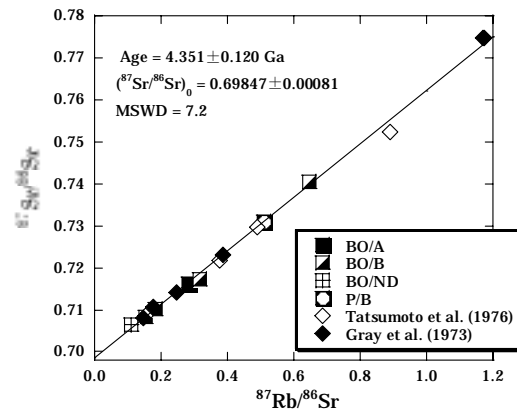


Fig. 3. Rb-Sr evolution diagram for the selected chondrules. Symbols are identical which used in figure 1. Decay constant $\lambda^{87}\text{Rb} = 1.42 \times 10^{-11} \text{ yr}^{-1}$ is used for age calculation